Earthquake Vulnerability Index of Buildings in Kota Kinabalu, Sabah, Malaysia

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ABSTRACT Sabah has experienced an increasing number of low to moderate seismic events throughout the years, owing to the presence of certain moderately active fault lines in the region. A significant earthquake struck in Ranau in 2015. Central and eastern Sabah, including Kota Kinabalu, were affected by the earthquake. Around 300 moderate magnitude earthquakes have occurred in this region during the last 150 years, ranging from M_W 2.5 to M_W 6.9. The majority of existing structures in Kota Kinabalu are based on wind and gravity loads, notably those built between the 1970s and 2000s. As a result, the inspection stages for building vulnerabilities are somewhat limited. The purpose of this study was to establish an earthquake vulnerability index for existing buildings in the city. The building databases contain information on the locations, structural and geometric properties of 247 structures that have been collected and analyzed. The obtained data is used to conduct an empirical assessment of the seismic vulnerability of existing buildings. Furthermore, this will be performed by employing a seismic vulnerability assessment with a score assignment, which is useful for analyzing a large number of buildings. Out of the total sampled buildings, the majority are classified as grade 3 and 4, suggesting a risk of severe structural damage. In comparison, only 5% of the population suffers from minor to no structural damage. In conclusion, the anticipated vulnerability index can be used to plan and carry out repair, reinforcing, and adaptation actions on existing structures that were designed and built without respect for earthquake loads. Such estimates may reveal weaknesses that should be avoided during the design and construction of new structures to avoid future earthquake damage.

KEYWORDS: Vulnerability Index; Kota Kinabalu building; Building; Earthquake; Sabah.
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Original Article

INTRODUCTION

In the past, earthquakes measuring up to 6.0 on the Richter scale have occurred in Sabah. Seismologists characterize the area as moderately to highly active (Alexander *et al.*, 2008; Chai *et al.*, 2009; Azhari, 2012). Large earthquakes in the Southern Philippines, the Straits of Macassar, the Sulu Sea, and the Celebes Sea also struck Sabah, and residents reported experiencing tremors during these events. In consequence, if a big earthquake of high magnitude occurs in neighbouring seismic zones, there is an increased danger of soil liquefaction and landslides. Sabah is bounded by the Sunda, Indo-Australian, and Philippines Sea plates, all of which are active, as part of Borneo's tectonically dynamic boundary (Hutchison, 2005). Seismicity was high near Kota Kinabalu's active Mensaban and Lobou-Lobou fault zones (Harith, 2016). The Belait, Crocker, Jerudong, Mensaban, and Mulu Faults, as well as the Pegasus Tectonic Line, are significant faults in Sabah. In Sabah's northwest, the Crocker fault zone is compressed from northwest to southeast. Looking at how strike slip occurrences correspond in the east reveals an apparent focal mechanism with NW compression. According to the fault mapping, the Crocker Range, which runs parallel to Kota Kinabalu, is 200 kilometres long. Figure 1 displays some of the city's fault lines as well as the distribution of earthquake epicentres with magnitudes ranging from M_W 2.5 to 6.9. In the last 150 years, this region has had over 300 moderate-magnitude earthquakes. The majority of Kota Kinabalu's contemporary structures are wind and gravity-loaded, especially those built in the 1970s, 1980s, 1990s, and early 2000s.

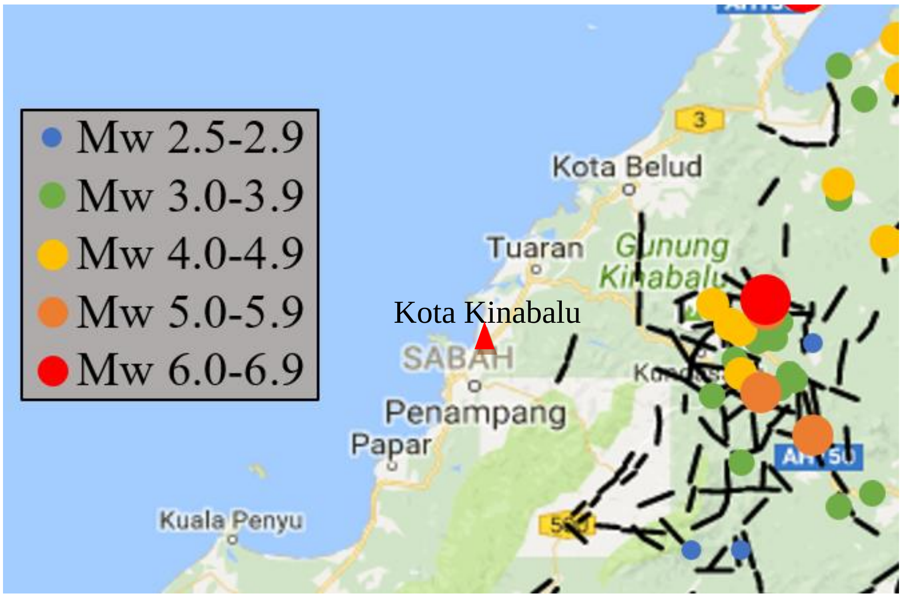

Figure 1. Within a 50-kilometer radius of Kota Kinabalu, the distribution of earthquake epicentres and fault lines (Kota Kinabalu in red triangle is stick in the map view).

According to the earthquake reports released in numerous newspapers and news broadcasts, it has been confirmed that several of the earthquake occurrences caused severe damage to the structures they passed through. The magnitude M*w* 6.3 earthquake that struck Lahad Datu on July 26, 1976, was the strongest ever recorded in Malaysia, causing the majority of damage to buildings (Phyllis *et. al*., 2015). On May 26, 1991, in the Ranau area, another earthquake with a magnitude of M*w* 5.1 caused relatively little damage to residential structures (Golutin, 2020). On June 5, 2015, in the same site, the second greatest seismic occurrence occurred, resulting in a magnitude 6.0 earthquake that damaged 23 schools and a mosque (Tongkul, 2015). In March of last year, a M*w* 5.2 earthquake shook Sabah, although there were no reports of damage. The same year, a massive M*w* 7.3 earthquake rocked the Celebes Sea, producing significant shaking in several buildings throughout Sabah. Meanwhile, just a few researches on building vulnerability have been undertaken in Sabah over the last 15 years.

Ghafar *et al*. (2015) employed a score assignment process based on observations to identify a seismically risky building in the Ranau area, and they used this information to develop their findings. Using this strategy, the author has amassed a total of around 717 public and private structures with a height of less than seven stories. According to the findings of the survey, about 34 percent of buildings require additional investigation into their structural flaws and the scores assigned to them. The same can be said for another study conducted by Mohamad *et al*. (2019), in which they conducted a score assignment technique and selected 22 public and private structures in Ranau that require additional investigation. The procedure for assigning scores has also been completed in the Semporna area. It was discovered by Safri *et al*. (2018) that practically all public structures in Semporna were classified as seismically risky. According to the most recent preliminary vulnerability research conducted by Jainih & Harith (2019), 60 percent of the buildings in Kota Kinabalu are classified as seismically risky, according to the study. The findings of the study indicated that additional research be conducted to determine their building performance.

METHODOLOGY

Structures' seismic behavior can be studied using the empirical method, which is one alternative to explore. This method makes use of straightforward building models that are based on a small number of input characteristics, such as the age of the structure, the kind of construction material, and the number of stories in the building. The effectiveness of a method increases when the input parameters required for evaluating the structures adequately characterize the whole seismic behavior of the buildings. Using this technology, a huge number of building stocks can be analyzed in a short amount of time. Quick assessment of structures based purely on visual examination and observation is required for the rapid visual screening (RVS) approach, which is intended for usage without completing structural calculations Buildings that may be seismically hazardous have been identified, inventoried, and screened using the RVS approach. Building types are defined by an assessor using a scoring system devised for the approach, which identifies the primary gravity load-carrying material of construction as well as the central seismic force-resisting system. Additionally, it's important to pinpoint structural elements that deviate significantly from the seismic performance of a typical building. Measures taken by RVS include survey preparation, survey implementation, and analysis and interpretation of research findings. After conducting a field survey and data collection in Sabah, researchers then selected and reviewed evaluation statements before moving on to actual fieldwork. In order to perform RVS, the steps listed below are performed.

Typology Classification of Sabah Buildings

Classifying the Sabah building based on its building typology (vulnerability class) is critical for understanding its structural and architectural configuration, evaluating its actual vulnerability, and developing an accurate structural model of the structure in question. Information about structures that are similar in function or specification is known as architectural typology. Age, construction materials, and the number of stories will be assessed for an estimated 247 structures in Kota Kinabalu. When selecting a sampling strategy for a particular building type, researchers should review relevant scientific journals and past earthquake vulnerability studies in the study region, as well as Google Maps and/or computational approaches based on Geographic Information System data sets.

Buildings ranging in height from low to high rise, a list of story heights is required, and the structures must be classified according to their type and intended use before the data can be gathered and analyzed. A low-rise construction can be as tall as three stories or as tall as 35 meters. Low-rise buildings are typically ones that do not have elevators, therefore being referred to as walk-up structures. The mid-rise building has a lot of windows and can have as many as five or six stories, depending on their height. Mid-rise buildings, in contrast to low-rise structures, which are typically not equipped with elevators and instead rely on stairwells, are typically provided with elevators. High-rise buildings, on the other hand, are those that are more than six stories or floors high. In addition, many high-rise buildings are over 100 meters in height and are not to be confused with skyscrapers, which are normally significantly taller and can reach heights of up to and including 200 m in height. The proper classification of a building's use and occupancy is a critical undertaking since it sets the tone for how a structure is designed in relation to its risk level. In order to ensure that a suitable level of protection is supplied to the building and its occupants, it is necessary to determine the appropriate occupancy classification for a building's components and characteristics.

Rapid Visual Screening RVS Survey

Using score assignment, a field survey is carried out on 247 structures in order to make a prediction about the number of damaged buildings that would result from a low to moderate magnitude earthquake. Previously collected soil investigation (SI) information for individual building stock locations was obtained from a recently published soil classification contour map, which was then represented using a Geographical Information System (GIS) and entered into the RVS screening form. The information was gathered through the RVS screening form, which is available online. Building inventory will be done during the sidewalk survey, and all building elements that may have an impact on their seismic performance will be visually examined and identified during the sidewalk survey, all of which will be included in the report. This exercise made use of the FEMA154 (2002) collecting forms, which were chosen based on the seismicity hazard zone level, such as Level 1 and Level 2 Forms for Very High, High, Moderately High, Moderate, and Low Seismicity, as well as Level 3 and Level 4 Forms for Moderately Low, Moderate, and Low Seismicity. The factors depicted in Figure 2 must be determined before the value of the Basic Score, Modifiers, and Final Score of the vulnerability index can be calculated.

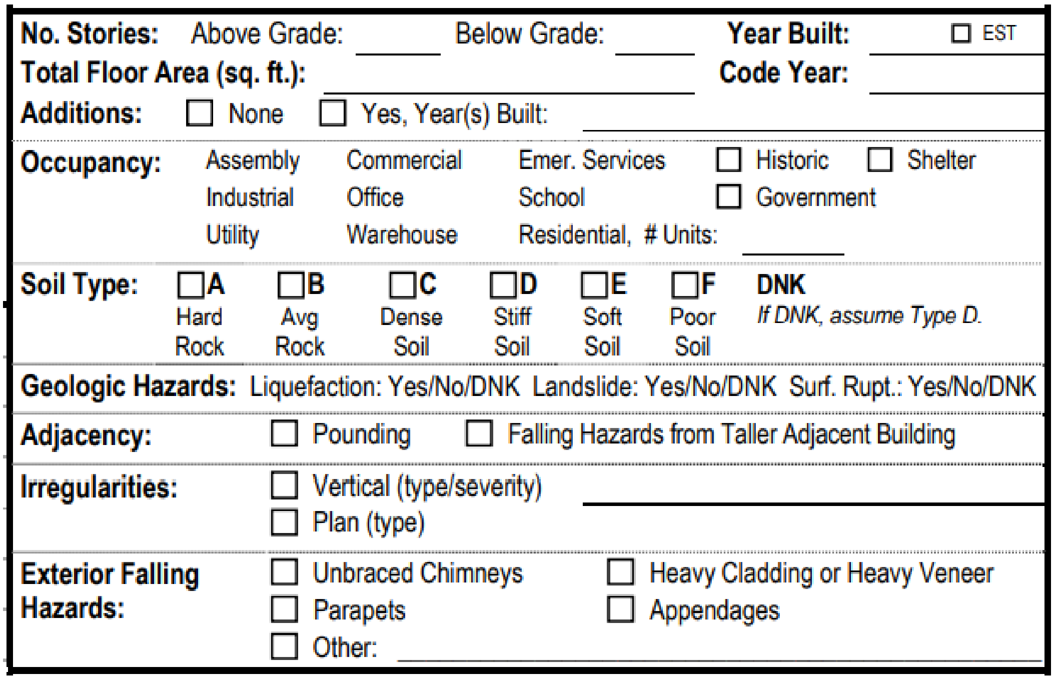
No. Stories: Above Grade: ____ Below Grade: ____ **Year Built:** ____ ☐ EST
Total Floor Area (sq. ft.): ____ **Code Year:** ____
Additions: ☐ None ☐ Yes, Year(s) Built: ____
Occupancy: Assembly, Commercial, Emer. Services, ☐ Historic, ☐ Shelter, Industrial, Office, School, ☐ Government, Utility, Warehouse, Residential, # Units: ____
Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil **DNK** *If DNK, assume Type D.*
Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK
Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building
Irregularities: ☐ Vertical (type/severity) ____ ☐ Plan (type)
Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer ☐ Parapets ☐ Appendages ☐ Other: ____

Figure 2. Building Information of Level 1 Data Collection Form (FEMA154, 2002).

Potentially high-risk level of building identification

The procedure described would lead to the identification of buildings that would be at risk in the event of a damaging earthquake, and it would be an integral part of the microzonation studies that are now being conducted in the Kota Kinabalu area. In order to determine all probable damages from a total of 247 buildings and to assign properly the buildings that have been categorised as high risk, further analysis must be performed on the risk identification process. Some details may not always be visible to the screeners, resulting in the screening of potentially seismically hazardous buildings that were missed otherwise. A simplified structural evaluation for each individual building, using an empirical method to forecast the actual building performance level under assigned local seismic excitation, is therefore advised for each individual building.

RESULT AND DISCUSSION

The study's findings indicate that 247 structures in Kota Kinabalu have been analysed for index vulnerability, and each piece of information gathered will be evaluated. Figure 3 summarised the number of buildings varying in height from low-rise to high-rise. Low-rise structures with one to three stories are classed as low-rise structures; medium-rise structures with four to six stories are defined as medium-rise structures; and high-rise structures with more than six stories are classified as high-rise structures. According to the statistics, during the 1970s and 2000s, the majority of buildings are greater than seven stories tall, accounting for 41% of all structures. Around 34% of buildings are medium-rise, whereas 25% are low-story.

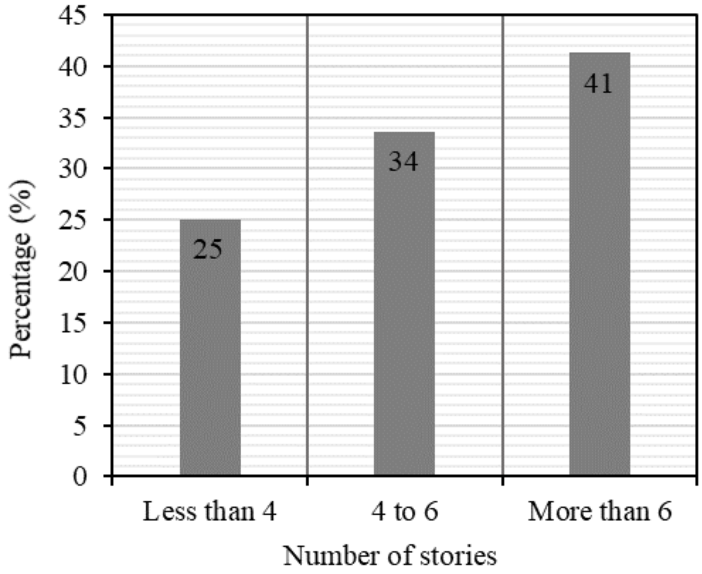

Figure 3. Buildings range number of stories

As illustrated in Figure 4, the office sector has the highest occupancy rate, accounting for 38% of the overall occupancy value across 247 buildings. Residential occupancy is the second most prevalent form of occupancy, accounting for 23% of total, followed by business and school occupancy, accounting for 17%. Kota Kinabalu is the state of Sabah's capital and main industrial center. The occupancy statistics reveals that Kota Kinabalu makes a major contribution to its inhabitants' political and economic well-being. The wave effect produced by an earthquake is not uniform over the Earth's land surface. The universe contains a variety of soil types, including hard rock, dense soil, muck, and man-made infill materials such as concrete. Within very small geographic areas, the distribution of soil types can be rather varied. As a result, two locations located at the same distance from the epicenter of an earthquake can have significantly different experiences.

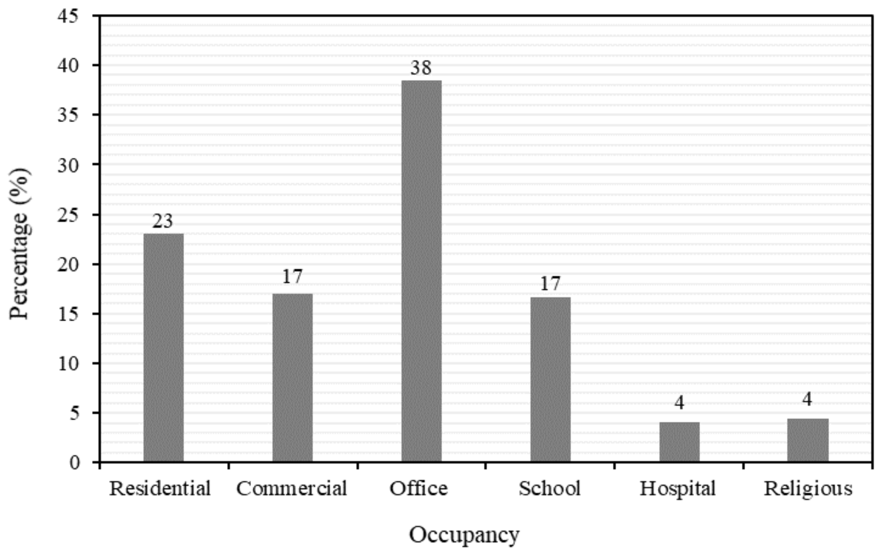

Figure 4. Percentage occupancy of buildings in Kota Kinabalu

As observed in this result, specific soil type information is often obtained from geotechnical engineering reports. If no soil microzonation maps exist for the area, the average shear wave velocity $V_{s,30,}$ can be used to estimate the soil type if the average shear wave velocity for the top 30 meter of soil is known. The soil investigation (SI) data for the Kota Kinabalu region's building stock were derived from a newly completed soil classification contour map by Kibat *et al*. (2019). Our information was used into this analysis, and as shown in Table 1, the majority of buildings in Kota Kinabalu are built on stiff soil.

Table 1. Soil investigation (SI) data for the Kota Kinabalu region

Soil Type	Number of Buildings
Hard Rock	1
Average Rock	1
Dense Soil	37
Stiff Soil	200
Soft Soil	4

Six separate site classifications have been established by the National Earthquake Hazards Reduction Program (NEHRP) based on the rock and soil types found in the area concerned. Hard rock is the toughest and produces the least amount of wave amplification, whereas soft soil is the polar opposite of hard rock and produces the greatest amount of wave amplification. In poor soil, there are only a few types of soil present, such as those that are susceptible to failure after an earthquake. The surveyed buildings in Kota Kinabalu were classified solely into six classes, as shown in Table 2 (details on building types can be found in Harith *et al*., 2021), with the majority of structures in the city being of the C1 (MRF) type, which is a fairly common construction type throughout Malaysia.

Table 2. List of building class in Kota Kinabalu

Building Type	Percentage (%)
C1 (MRF)	66
C2 (SW)	9
C3 (URM INF)	18
PC2	4
S4 (RC SW)	2
S1 (MRF)	2

In the following step, the RVS score is compared against possible damage scores, which are calculated in accordance with FEMA154 (2002) using the information gathered from the RVS field survey. Building damage is classified into five grades according to the European Macroseismic Scale (EMS-98), with Grade 1 being the most severe and Grade 5 being the least severe. Following an earthquake, the damage classifications are useful in determining the intensity of the earthquake. In order to categorize the damage probabilities, they were separated into five categories, with Grade 1 having the lowest probability and Grade 5 having the highest. Generally speaking, Grade 1 ($S > 2.5$) represents negligible to slight structural damage, Grade 2 (S 2.5) represents moderate structural damage, Grade 3 (S 2.0) represents significant structural damage, Grade 4 (0.7) represents extremely heavy structural damage, and Grade 5 (S 0.3) represents complete structural destruction. According to the data, the vulnerability index of buildings in Kota Kinabalu falls into the categories of Grade 2 to Grade 5 as shown in Figure 5. The greatest number of structures can be identified in the range of scores between 0.7 and 2.0 points. Structures in this category account for 91 percent of all structures.

Surprisingly, 3% of the structures are classified as Category 5, which means that additional detail analysis in terms of structure performance must be carried out for these structures, and additional necessary investigations into the seismic susceptibility of these structures must be carried out in the future.

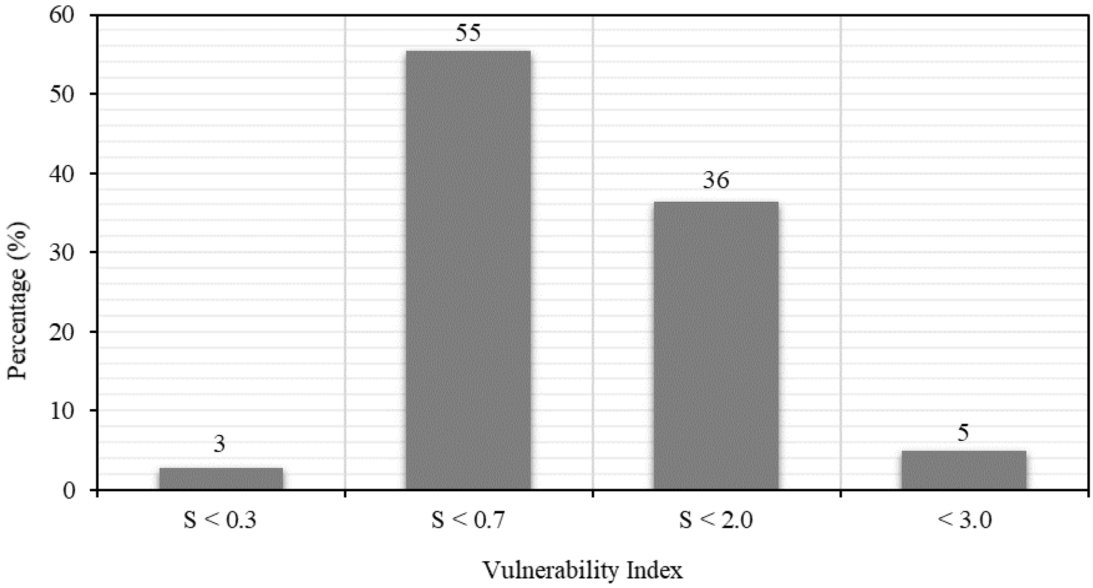

Figure 5. Vulnerability Index of Kota Kinabalu building.

CONCLUSION

Following the results of the vulnerability index, it was discovered that the vast majority of buildings in Kota Kinabalu had damage levels 3 and 4, indicating that they had suffered substantial structural damage. Meanwhile, only 3% of structures have a structural score greater than or equal to less than 0.3 on the vulnerability index, indicating serious structural damage ranging from near collapse to catastrophic collapse. Construction of extra thorough vulnerability studies will be recommended for buildings with an RVS score of less than 2.0, because the tolerable probability of collapse in current structures is roughly 2.0. This shows the need for further inquiry and more specific measures to be taken.

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